Ultra-Efficient Engine Technology Program

Fiscal Year 2002
Performance Report

Message from the UEET Program Manager

We in the UEET Program Office are pleased to provide this Fiscal Year 2002 Performance Report to our many interested customers, stakeholders, and partners. The UEET Program is NASA's turbine engine technology program that addresses critical environmental issues facing the 21st century air transportation system. The technologies being developed in the UEET Program will enable members of the U.S. propulsion community to design and manufacture future generations of commercial gas turbine engines that will be leaders in the global aerospace market. In addition, many technologies being developed in the UEET Program directly benefit the Department of Defense (DoD), and aggressive efforts continue to ensure these technologies are transitioned to the DoD to support important, national security needs.

The President's Management Agenda (PMA) has challenged all federal agencies to improve the relevance and performance of the programs for which they are responsible. We believe the UEET Program has strong, positive answers to the three questions that encapsulate fundamental PMA challenges:

- Is this program needed?
- Is it a wise use of the organization's finite resources?
- Could these resources be used better elsewhere?

We believe the UEET Program demonstrated outstanding cost, schedule, and technical performance over the past fiscal year. High-quality performance does not come by accident. Rather, it comes from solid, well-devised and executed plans, and outstanding dedication of the personnel on our UEET team. These people come from NASA, industry, and academia, forging a multitalented, visionary group. Testament to this fact is that in FY 2002, the UEET government management team was recognized by NASA's Project Management Shared Experience Program in a showcase of the Agency's best projects. This award is a distinguished honor for the commitment shown by the UEET Program's management personnel.

The President's Aerospace Commission on the Future of the U.S. Aerospace Industry issued its final report in 2002. This document is providing guidance to national aerospace policy and decision makers on critically important steps that must be taken if the U.S. is to retain global leadership in the 21st century. The UEET Program aligns well with this document's recommendations.

Our Administrator, Sean O'Keefe, has committed that NASA will work more closely with and support DoD in providing for the national security needs of our country. Personnel in the UEET Program continue to work closely with DoD personnel in the Integrated High Performance Turbine Engine Technology (IHPTET) program to develop collaborative technological development efforts as well as transition UEET technologies to support the IHPTET Program wherever appropriate. The UEET and IHPTET programs together are providing turbine engine technology leadership for commercial and military applications.

Again, we invite you to read this report and form your own conclusions. We sincerely value your comments and feedback. Please feel free to contact me at (216) 977–7135 or robert.j.shaw@nasa.gov. You are also encouraged to follow the progress of the UEET Program by visiting our website (www.ueet.nasa.gov).

Dr. Robert J. Shaw
NASA UEET Program Manager

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Executive Summary

The UEET Program has proudly completed another outstanding fiscal year of cost, schedule, and technical performance. Six of seven level one milestones were accomplished, an achievement that becomes even more impressive when coupled with the fact that 18 of 19 level one milestones have been completed over the course of UEET's life (FY 2000–2002).

UEET has successfully transitioned ultra-low NO_x combustor technologies from laboratory flame tubes (TRL3) to sectors (TRL4). Initial sector tests in NASA Glenn's Advanced Subsonic Combustion Rig facility demonstrated 67% NO_x reduction. This first round of testing gives us increased confidence we can meet the UEET Program goal of 70% NO_x reduction demonstrated in annular rig tests (TRL5).

The program has also completed the full-scale rig test of a Ceramic Matrix Composite (CMC) liner in partnership with General Electric (GE). Successful rig tests resulted in a "green light" decision for a NASA/GE partnership engine demonstration test in FY 2002. A CFM56 engine testbed will be used to mature CMC technology to TRL6 level of readiness and thus hasten the technology transfer/insertion process. Incorporation of CMC liners into future engine designs is projected to reduce cooling airflow requirements and thus reduce engine fuel burn (contributing to the UEET fuel burn reduction goal).

Advanced turbine engine technologies are useful only if they can be utilized in future engine designs. For commercial turbine engines, time- and cost-effective certification processes are necessary for the inclusion of advanced technologies. UEET has formed a partnership with the Federal Aviation Administration (FAA) to explore certification challenges associated with CMCs. The results of this pilot effort will be used to develop other advanced technology pre-certification efforts for UEET technologies.

Various industry partners have completed studies to assess UEET technological benefits for small thrust class and access-to-space engines. These studies' results demonstrated that UEET technologies possess strong potential in various applications and will be used to ensure that the technologies are utilized for the maximum benefit in future turbine engine designs.

UEET has completed an engine architecture/pay-off study for the impact of its Intelligent Propulsion Controls (IPC) technologies. It determined that the IPC Project will contribute to the technology foundation for the next paradigm shift in turbine engines-intelligent engines. Future intelligent engines will have the capability to independently maximize performance across the mission profile while minimizing emissions and noise signatures. The striking impact that IPC technologies represent is an impressive collection of innovative research and forward thinking.

The Dual Spool Turbine Facility (DSTF), a unique new facility designed to facilitate improved understanding of fluid physics in closely-coupled, highly-loaded turbine concepts, will be located at NASA Glenn. Its design review is 60% complete and NASA has secured partnership commitments from DoD as well as several industry partners to share facility design and utilization in conducting technology development efforts. DSTF will become operational in FY 2005 and the UEET Program is especially proud of this fact given its funding role in the facility planning and development.

The President's Aerospace Commission Report is a multi-year effort completed in FY 2002 and delivered to The White House in November. Its objectives include assessing the domestic aerospace industry's future importance for U.S. economic and national security. The report was commissioned by Congress as part of its FY 2001 budget and outlines nine recommendations provided to national policy and decision makers in government and industry on steps that must be taken if the U.S. is to retain its global aerospace leadership position.

The UEET Program is uniquely poised to successfully address two of these recommendations:

- *#9 Government should increase investment in breakthrough technologies, including those for propulsion and power as well as emissions and noise reduction.*

UEET can accept the challenge of this national policy document and deliver emissions reduction technologies required for turbine engine applications as well as turbine engine performance improvement technologies that will directly benefit future commercial and military engines.

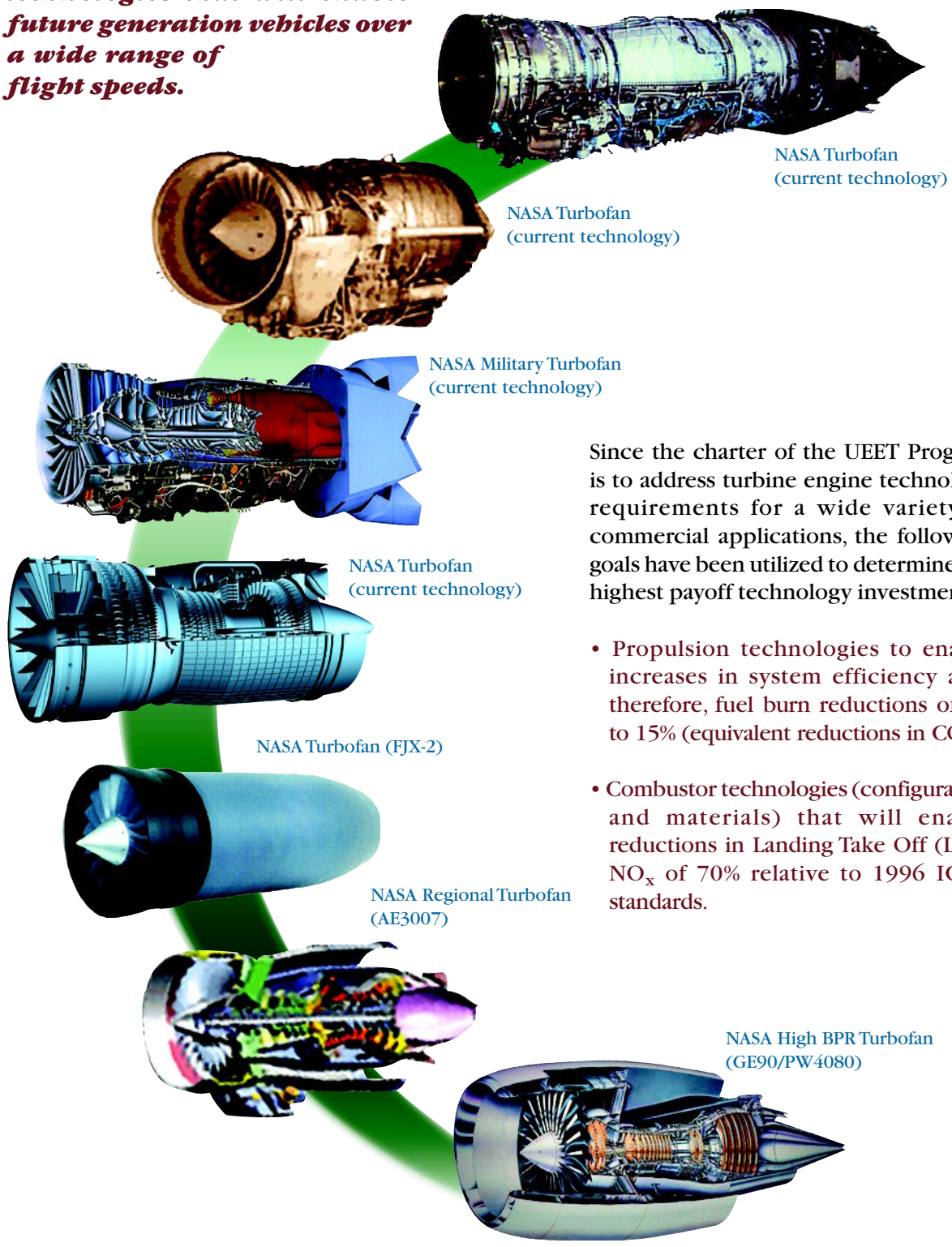
- *#8 Government should promote the growth of a scientifically and technologically trained U.S. aerospace workforce.*

UEET's aggressive education/outreach plan directly supports this recommendation with its innovative products that include multilingual, interactive, aerospace games, educational CD-Roms, and materials such as bookmarks and brochures. The education/outreach plan reaches student audiences ranging in age from K–12 by inspiring interest in the aerospace arena.

In closing, the UEET Program has had a busy, but fulfilling year and is already immersed in new efforts to further its ambitious mission in support of NASA's Aerospace Technology Enterprise theme areas.

As NASA's turbine engine technology program, the vision of the UEET Program is to:

Develop and hand off revolutionary turbine engine propulsion technologies that will enable future generation vehicles over a wide range of flight speeds.



NASA Turbofan (current technology)

NASA Turbofan (current technology)

NASA Military Turbofan (current technology)

NASA Turbofan (current technology)

NASA Turbofan (FJX-2)

NASA Regional Turbofan (AE3007)

NASA High BPR Turbofan (GE90/PW4080)

Since the charter of the UEET Program is to address turbine engine technology requirements for a wide variety of commercial applications, the following goals have been utilized to determine the highest payoff technology investments:

- Propulsion technologies to enable increases in system efficiency and, therefore, fuel burn reductions of up to 15% (equivalent reductions in CO_2).
- Combustor technologies (configuration and materials) that will enable reductions in Landing Take Off (LTO) NO_x of 70% relative to 1996 ICAO standards.

The technology payoff assessments are made utilizing the results of NASA in house, university, and corporate partner propulsion and airframe systems studies. For the NASA and university studies a series of reference propulsion systems and air vehicles are utilized, as shown in Figure 1. These reference systems are meant to be representative of the current state of the art for each vehicle class and therefore are the baselines against which technology contributions are assessed. A second set of reference systems and vehicles also shown in Figure 1 are utilized to evaluate technology synergy opportunities for applicability of the UEET technologies to future general aviation, military, and access to space applications. These study results help in defining the broadest applicability of the technologies and therefore the greatest return on the taxpayer's investment.

The seven projects that comprise the UEET Program are shown in Figure 2. NASA Glenn

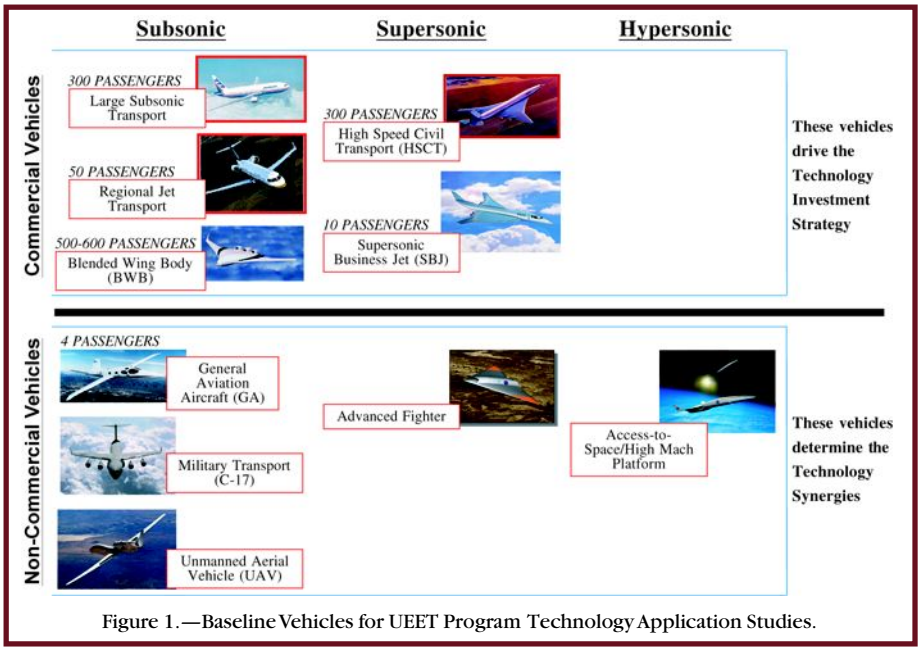


Figure 1.—Baseline Vehicles for UEET Program Technology Application Studies.

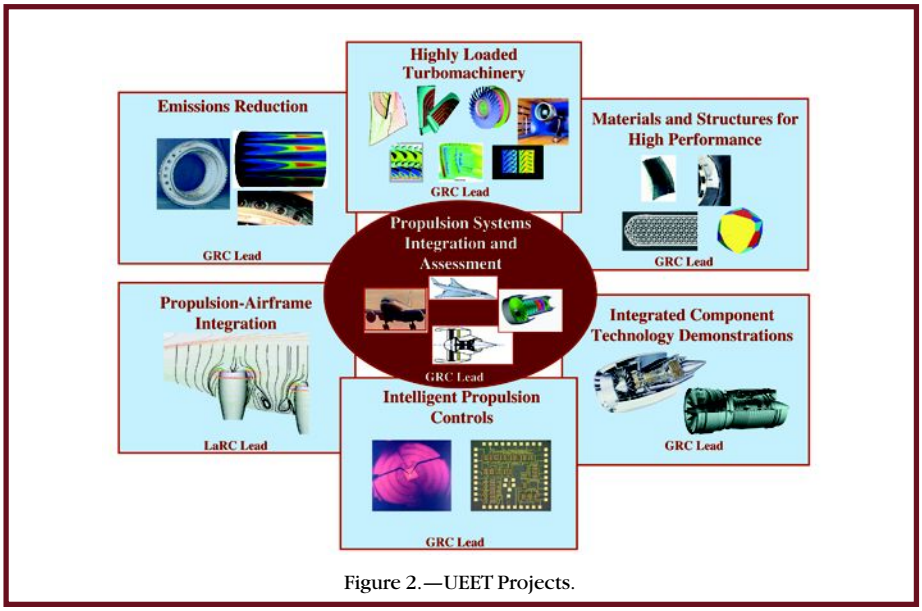


Figure 2.—UEET Projects.

Research Center has been designated to be the lead center for the UEET Program with level one (program) management responsibility being assigned to the UEET Program Office. The seven projects that comprise the UEET Program have active involvement from NASA's Langley, Ames, and Dryden Research Centers as well as the Goddard Space Flight Center. In addition, the UEET Program has eight aerospace companies (Allison-Rolls Royce, Boeing, General Electric Aircraft Engines, Honeywell, Lockheed Martin, Pratt & Whitney, Williams International, and Gulfstream), the Turbine Engine Division of the Air Force Research Labs and one university (Georgia Tech) who have teamed with NASA to execute the program in a partnership fashion. Figure 3 indicates these partners have committed to work with NASA to ensure program success, including providing direct in-kind contributions to complement the government resources provided by NASA.

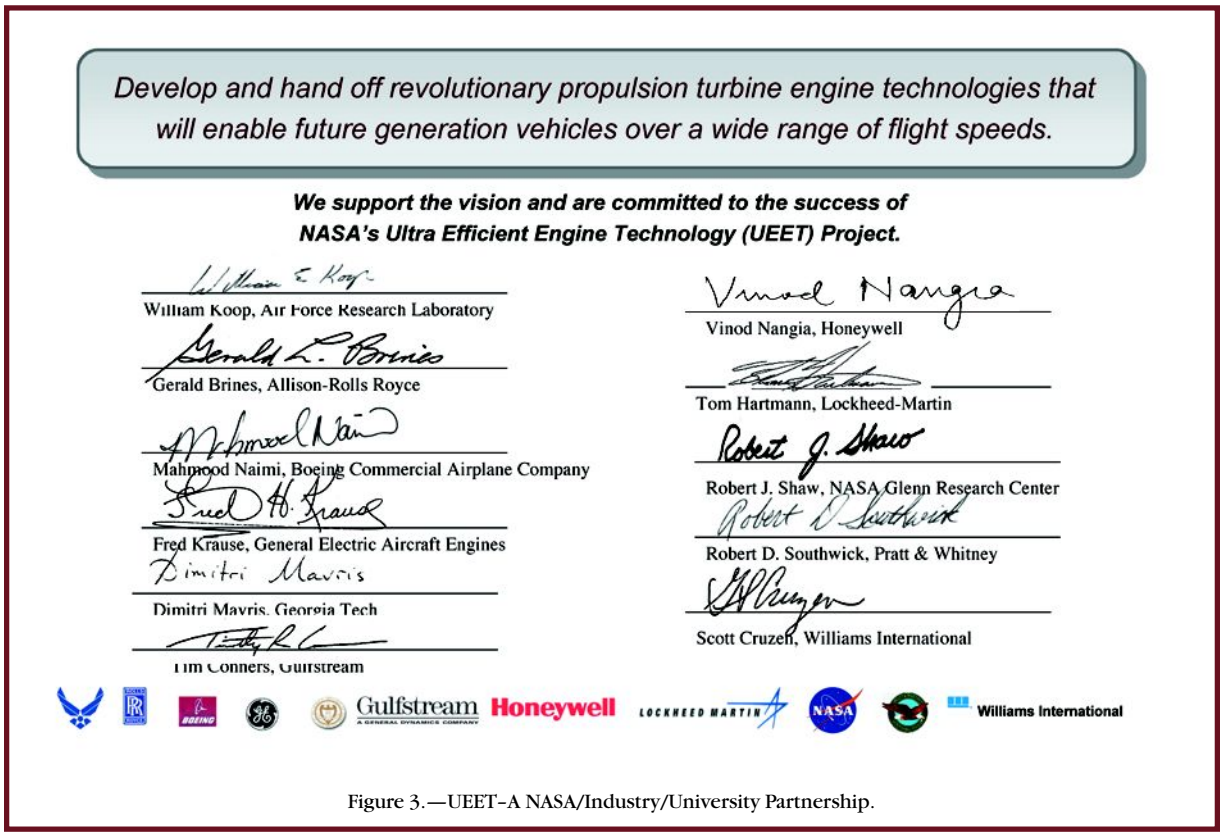


Figure 3.—UEET–A NASA/Industry/University Partnership.

The most recent technology payoff assessments from the NASA in house propulsion and airframe systems studies are shown in Figure 4. Study results indicate that UEET's current technological portfolio is projected to meet if not exceed the program goals for both fuel burn reduction and LTO NO_x reduction. However, the amount of test data acquired to date is limited–especially for the technologies that contribute to reduced fuel burn–thus creating a large uncertainty in the current predictions. As the UEET Program acquires critical data through experimental and analytical efforts planned for the program's outyears, assessments will be updated and uncertainty will be considerably reduced. The UEET Program Office is working with Georgia Tech to institute a disciplined approach to metrics tracking, including employing a probabilistic approach to quantify the uncertainty in the technology payoff projections.

October 2002

Goal	Status	Remarks
15% fuel burn reduction for large subsonic	22% projected for 300 PAX	Systems studies projections of combined impacts of UEET technologies.
8% fuel burn reduction for small subsonic, small / large supersonic	15% for 50 PAX 17% for 300 PAX HSCT 37% for 10 PAX SSBJ	Limited test data (TRL2-3+ range)
70% N0x reduction (below ICAO 96) for subsonic (large regional) combustors over the LTO cycle	Initial industrial sector tests give confidence that at least the min success will be achieved (TRL = 3+)	Initial sector tests completed

Figure 4.—Program Status.

Performance Summary

Technical

Figure 5 depicts the current baseline level one schedule for the UEET Program. Six level one program milestones were completed during fiscal year 2002; five that had been planned for FY02 and one—2200 deg CMC Liner Demo—that had been delayed from FY01 due to flooding at the contractor's test facility. Over the first three years of the UEET Program, eighteen of eighteen baselined level one milestones have been successfully completed.

For the UEET Program, the phrase "successfully completed" means that at least the minimum success criteria were reached for the milestone. The target objective and the minimum success criteria for all UEET Program level one milestones over the life of the program have been developed and are available in the program plan.

Appendix A contains more detailed descriptions of the technical accomplishments for each of the six level one milestones completed in fiscal year 2002.

Schedule

Relative to the current baseline level one schedule for the UEET Program, five level one program milestones were scheduled for completion during fiscal year 2002. All five were accomplished within 30 days of the baseline schedule dates. One level one milestone open at the end of fiscal year 2001 was accomplished in fiscal year 2002 within six months of the planned accomplishment date.

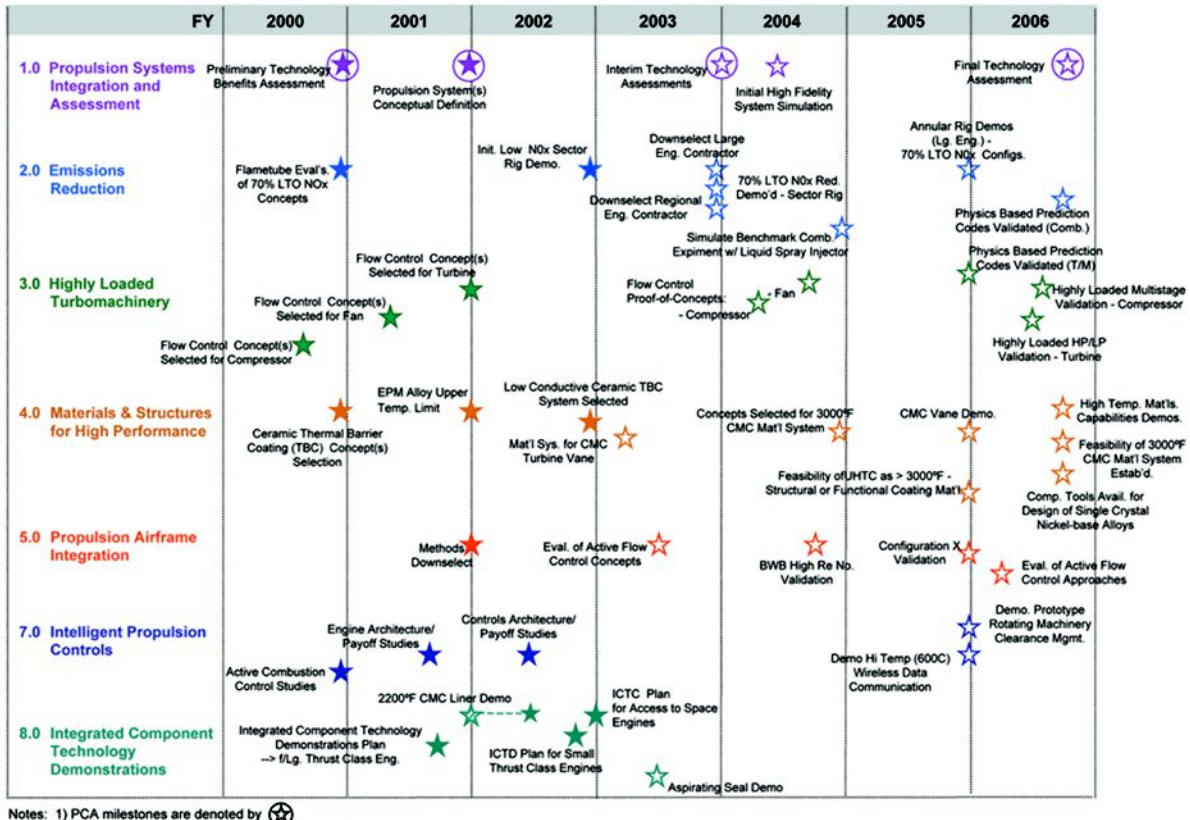


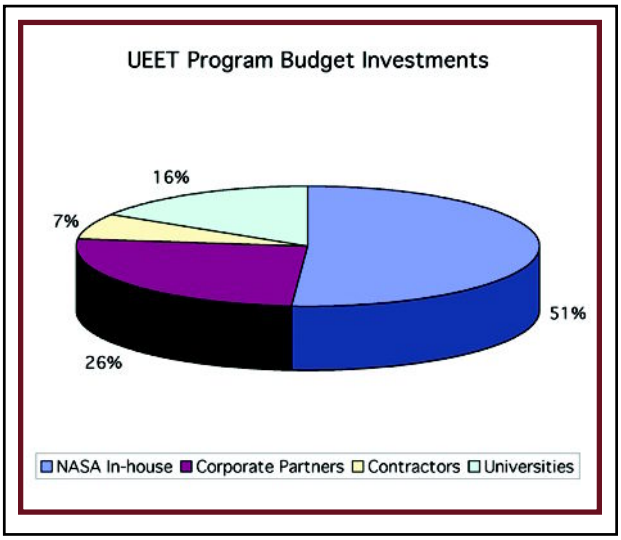
Figure 5.—UEET Level 1 Milestone Schedule.

Resources

The overall life cycle budget (Gross R & D) for the UEET Program is as follows:

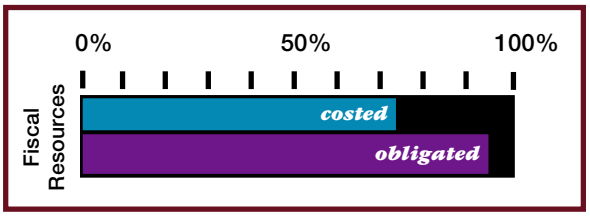
Fiscal Year/$M						
00	01	02	03	04	05	06
70	48	50	50	50	50	50

The fiscal year 2002 budget authorized by Congress was invested as follows:



Included in the NASA in-house investments was $2M for the design of a dual spool, counter rotating turbine test facility, which will be constructed utilizing UEET Program resources and will be located at NASA Glenn.

Timely, proper utilization of resources is critical to the success of any program, and in fiscal year 2002, the UEET Program:



obligated 94.4% costed 73.6%

of the fiscal resources for which the program office was responsible.

In fiscal year 2002, the UEET Program was allocated 213 civil servant work years at the NASA centers involved in the program. Over 172 work years were utilized to execute the program during the fiscal year.

External Reviews

Two independent assessment reviews were conducted during the past year. First, a group chartered by NASA's Aerospace Technology Enterprise (Code R) gave the UEET Program high marks for the project management practices followed including the risk management process being followed.

A second, more in depth assessment was conducted as chartered by the Chief Financial Officer (CFO) of NASA's Glenn Research Center. This review resulted in the CFO validating the cost to complete projected by the UEET Program.

External Partnerships

External Partnerships

The UEET Program has continued to proactively seek meaningful partnerships with other NASA and federal government programs as well as (where appropriate) international programs to achieve more rapid, cost-effective technology development and transfer. During fiscal year 2002, the program's efforts began, sustained, or renewed the following beneficial relationships:

Department of Defense/Department of Energy

The UEET Program is a full partner in the ongoing efforts between NASA, the Department of Defense (DoD), and the Department of Energy (DoE) to determine technology synergy and collaboration opportunities within existing programs. In fiscal year 2002, collaborative efforts between UEET, the Air Force and DoE were identified in the area of high-temperature engine materials (i.e. ceramic matrix composites, turbomachinery disks, and turbine airfoil material systems). Specific working relationships were agreed to and documented in formal interagency agreements. Also NASA Glenn personnel involved in the UEET Program collaborated with personnel from the Air Force's Wright Patterson and the Navy Patuxent River Laboratories to conduct an emissions characterization tests of a military combustor and engine.

Environmental Protection Agency

UEET, in partnership with the Environmental Protection Agency's (EPA) Office of Atmospheric Programs, completed a health impact study to assess the projected impact of a possible future fleet of supersonic commercial aircraft and published a NASA contract report on the subject.

Federal Aviation Administration

UEET negotiated and signed an interagency agreement with the Federal Aviation Administration's (FAA) Office of Environment and Energy to continue partnership efforts relative to commercial engine emissions characterization and understanding.

Additionally, three areas of the FAA—its Engine & Propeller Directorate, Standard & Policy Branch and Engine Certification Office—have partnered with NASA to implement steps towards an improved insertion of emerging technologies into commercial aircraft. UEET was selected to develop the Joint Technology Certifiability Program (JTC). FAA personnel will work with researchers from NASA's UEET Program to develop the framework. The program will continue the highest commitment to safety while exploring paths to insert new technologies. Ceramic Matrix Composites (CMC) technology, developed for gas turbine applications under the UEET Program, has been selected as the technology to initiate the insertion process. The program will identify key impediments to the insertion of NASA technology by addressing issues that arise during the certification process. Strong participation is expected from the gas turbine industry. Currently, the team is exploring certification training to understand the issues facing propulsion certification for material substitutions.

QinetiQ — United Kingdom

UEET conducted two partnership tests with QinetiQ to measure the emissions characteristics of an isolated combustor and a full engine system including the same combustor configuration. The data sets acquired are used to validate the emissions predictive tools being developed by the UEET Program. To date, two reports have been published on collaborative data and one journal paper has been submitted for possible publication.

Education and Outreach

The UEET Program has an aggressive Education and Outreach component that encourages the public to support NASA's mission and vision while inspiring children in grades K-12 to pursue careers in science and engineering. Efforts are specifically focused on commercial aviation and gas turbine engine themes, but broadly impact the public with a multi-faceted approach.

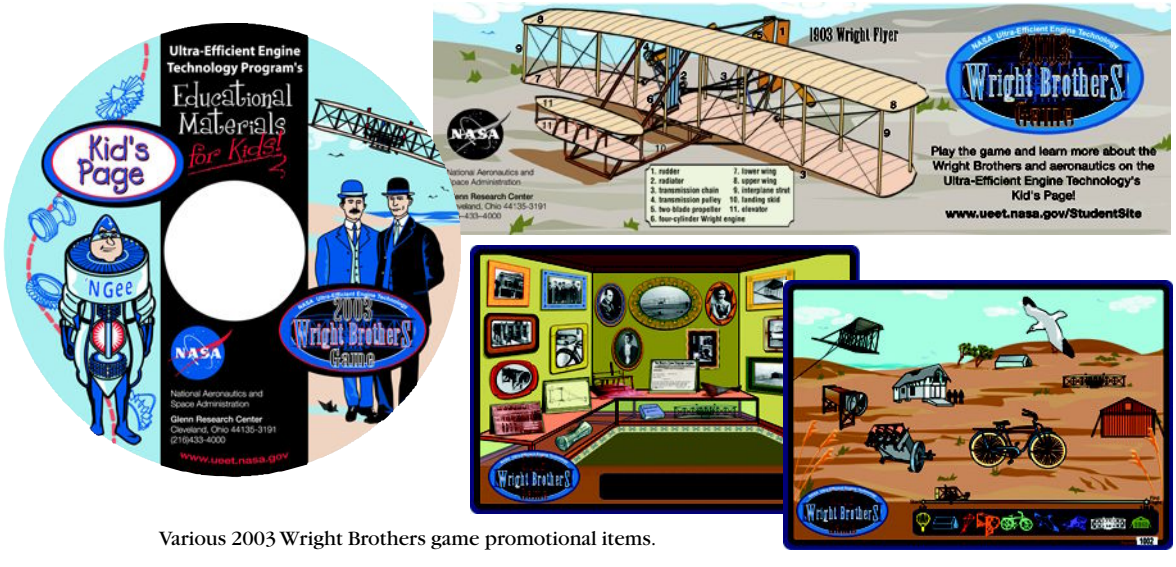
A wealth of outreach materials has been created and distributed this year, including the following: informational UEET tri-fold brochures that describe the program's technologies; a Wright Brothers CD-Rom game that teaches children in grades 5–8 about the scientific process used to discover powered flight; Wright Brothers bookmarks that outline the history of flight as well as provide student resources; a UEET project display to translate the program's scope and focus to the public; and finally, Johnny's Airport Adventure, a UEET-developed storyboard designed for classroom role playing, is available to educators in Spanish and English.

Johnny's Airport Adventure storyboard


Young Astronaut Day

that provides the latest and greatest information to the UEET community and the annual UEET Performance Report, which provides metrics of program success. What's more, during this past fiscal year alone, program personnel organized and staffed major events including conferences, seminars, and workshops: Young Astronaut Day, Cleveland, OH; Engineers' Week, northeast OH; Airport Air Quality Symposium, San Diego, CA; and EAA AirVenture, Oshkosh, WI.

UEET is equally as committed to sharing its knowledge and experience with its stakeholders and partners as with the nation at large. Towards this end, program management established two new marketing tools: the UEET Insider, a quarterly newsletter



Various 2003 Wright Brothers game promotional items.

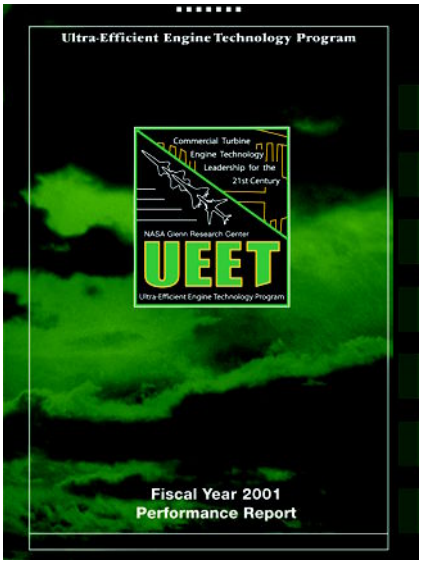
Education and Outreach—cont'd.

The program's active outreach methods even resulted in a bit of media exposure by being featured on a TV show called "Destination Tomorrow" and in various print venues including Agency communications such as NASA Explores as well as in more internationally-respected publications such as Aviation Week.

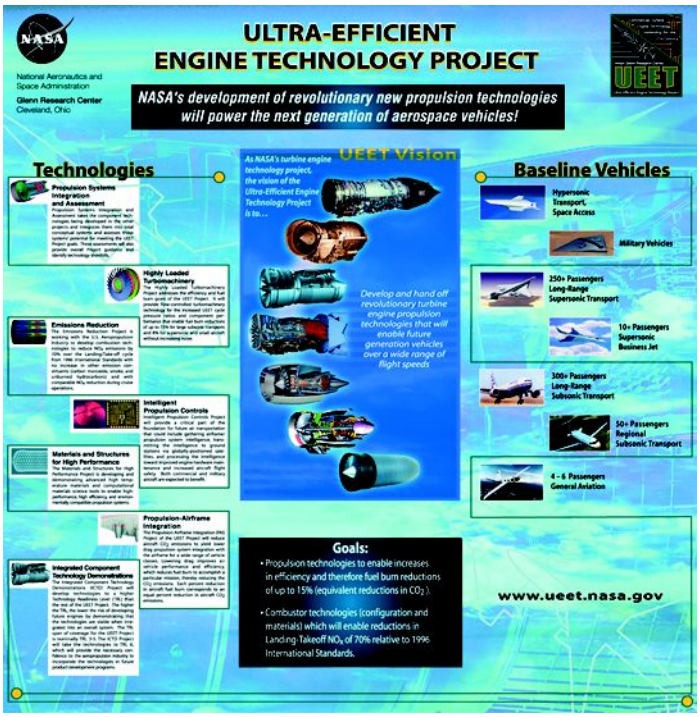
All NASA Aerospace Technology Enterprise (Code R) programs are required to have education/outreach plans and as has been illustrated, UEET takes this responsibility seriously. Future plans include the development of more multilingual, interactive teaching tools and more public visibility via program presence at U.S. Centennial of Flight celebrations and other locations.

UEET Program feature on TV show, *Destination Tomorrow*.

Media Exposure in Agency communications such as *NASA Explores*.



Annual UEET Performance Report provides metrics of program success.



UEET Project Display translates the program's scope and focus to the public.

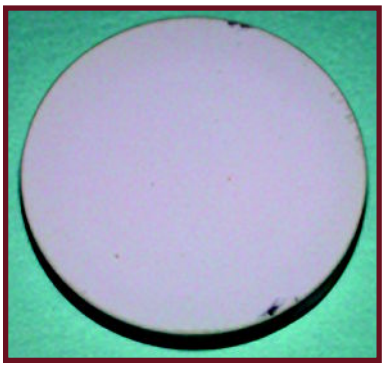
Technology Transfer

Twin annular pre-swirl (TAPS) combustor

Research conducted under the UEET Program naturally lends itself to technology transfer with the U.S. aerospace industry because its disciplines directly impact the field. UEET's commercialization efforts do not stop at the obvious, though. Rather, the program strives to transfer and commercialize select UEET technologies for the benefit of U.S.-owned, non-aerospace industries as well, thus widening its sphere of influence. To achieve this goal, UEET relies upon strong intellectual property management strategies. UEET partners with the National Technology Transfer Center (NTTC) and NASA Glenn's Commercial Technology Office in order to achieve successful technology partnerships. Wherever possible and appropriate, UEET utilizes cost sharing partnerships as the mechanism for the technology transfer process.

In fiscal year 2002, the UEET Program accumulated several notable technology transfer accomplishments:

General Electric Aircraft Engines (GEAE) recently completed double annular testing of the twin-annular pre-swirl (TAPS) low-emissions combustor technology in a full-annular combustor, representing a technology readiness level (TRL) 5. This initial TAPS low-emission combustion technology was developed under the NASA Advanced Subsonic Technology (AST) Program with a goal of 50% NO_x reduction from the 1996 ICAO regulation. This recent testing under UEET demonstrated the goal level of 50% NO_x reduction with necessary margins for development.



Low Conductivity Thermal Barrier Coating Sample

As stated in a recent Aviation Week article: "The combustor for the 7E7 power-plant is expected to feature a derivative of the twin-annular pre-swirl (TAPS) technology…"[1] This power-plant will be utilized in Boeing 7E7 aircraft, a next-generation, 250-seat, environmentally-friendly transport. UEET continues to develop TAPS low-emission combustion technology with a new goal of 70% NOx reduction from the 1996 ICAO regulation, thus increasing its potential technology transfer capabilities with industry. In fact, according to the same article, "GE is so encouraged by these results that it is considering the TAPS combustor technology for potential military applications."[2]

UEET has also developed a low conductivity Thermal Barrier Coating (TBC) that will significantly increase temperature capability of both high-pressure turbine and combustor liner components. The TBC can thereby increase engine turbine efficiency and reduce emissions, and further processing modifications could improve the coating process even more. The material has been so successful that commercial interest in this patent-pending technology is imminent. In fact, there is already an interest within the Department of Defense (DoD) Integrated High Performance Turbine Engine Technology (IHPTET) Program due to benefits of the new TBC that have already been demonstrated in test rig components requiring greater thermal protection. There is also a growing interest in this coating for industrial gas turbine use. Future efforts will focus on process development and scale-up with various rig and engine demonstrations.

[1] *Aviation Week & Space Technology, March 12, 2003 edition, p. 40.*

[2] *Ibid.*

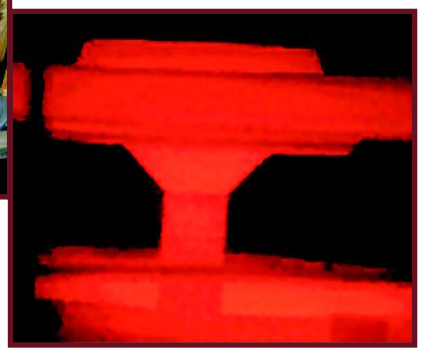
Technology Transfer—cont'd.

Not only does UEET pursue new avenues for technology transfer, but it invests in the improvement of existing technologies with promise for future, innovative benefits.

As an example, the advanced alloy "ME3," an increased-temperature, nickel-based, powder metal alloy, developed jointly with General Electric (GE) and Pratt & Whitney, although featured as a previous technology transfer accomplishment, recently progressed to more exciting stages. ME3 was designed to increase the life of jet engine parts, but has been determined to also increase fuel efficiency. Engine disks created from ME3 can endure "hot times" up to 30 times longer than disks currently being used before requiring overhaul. Future jet engines will enjoy greater fuel efficiency as a result of higher temperatures enabled by ME3. As both commercial and military applications are being aggressively pursued, the first real success story for this material will be in GP7200 engines for the Airbus A380. The "more environmentally responsible" A380, scheduled to enter into service in 2006, is projected to be the largest, most advanced and efficient commercial airliner ever conceived, with operating costs between 15% and 20% lower than any competitor aircraft.

Evaluation of ME3 Forgings

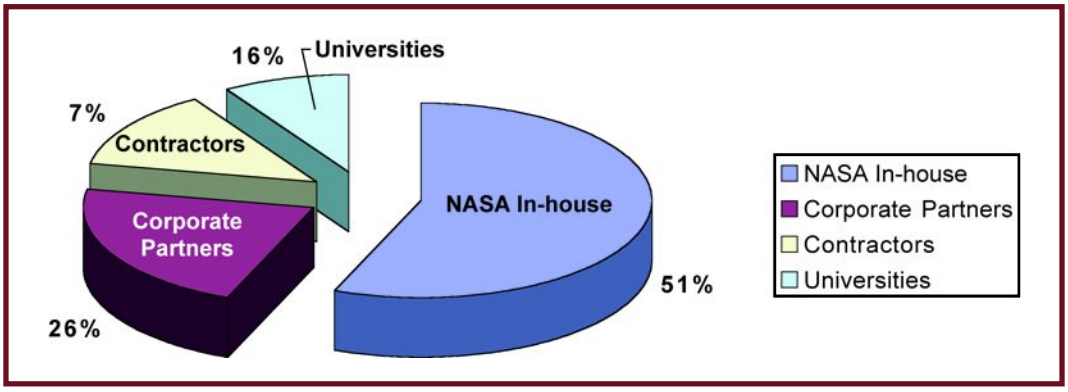
Inspection of ME3 Forgings



ME3 Material Being Forged

Resource Investment Details

In fiscal year 2002, the UEET Program budget was invested as follows:



The more detailed list of participants is as follows:

NASA In-house

- Ames Research Center (CA)
- Dryden Flight Research Center (CA)
- Glenn Research Center (OH)
- Goddard Space Flight Center (MD)
- Johnson Space Center (TX)
- Langley Research Center (VA)
- NASA Headquarters (DC)

Corporate Partners

- Allison-Rolls Royce (IN)
- Boeing (CA)
- General Electric Aircraft Engines (OH)
- Georgia Tech Research Corp. (GA)
- Honeywell (AZ)
- Lockheed Martin (CA)
- Pratt & Whitney (CT)
- Williams International (MI)

Other Government Agencies

- U.S. Air Force Systems Command (TN)
- U.S. Department of Transportation /FAA (DC)
- U.S. Department of Defense (OH) (MO)
- U.S. Energy Department (IL)
- U.S. Environmental Protection Agency (DC)

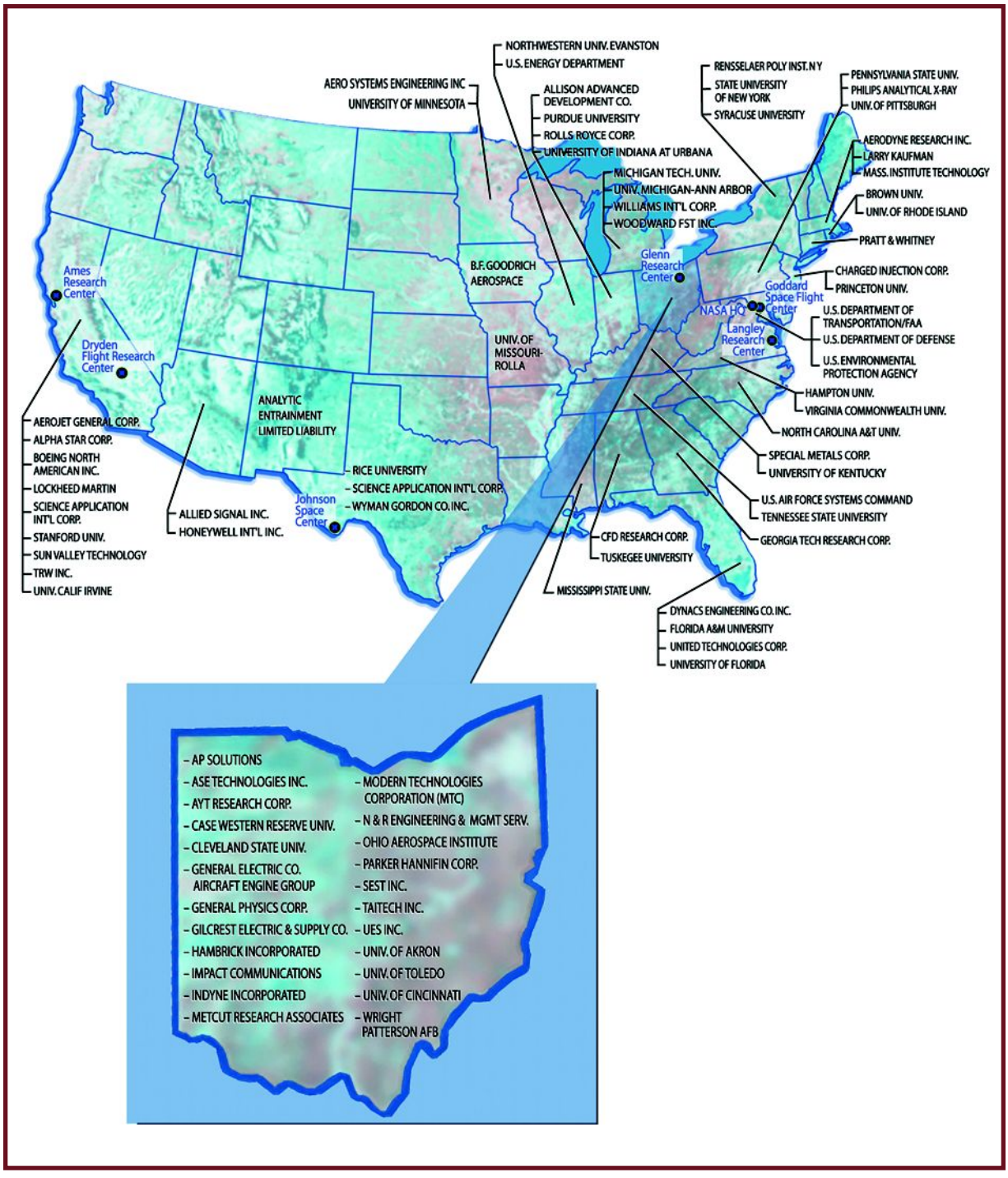
Contractors

- Aero Systems Engineering Inc. (MN)
- Aerodyne (MA)
- Aerojet General Corp. (CA)
- Allied Signal (AZ)
- Alpha Star Corp. (CA)
- Analytic Entrainment Limited Liability (NM)
- AP Solutions (OH)
- ASE Technologies Inc. (OH)
- AYT (OH)
- B.F. Goodrich (IA)
- CFD Research Corp. (AL)
- Charged Injection Corp. (MD)
- Dynacs Engineering Company Inc. (FL)
- General Physics Corp. (OH)
- Gilcrest Electric and Supply Co. (OH)
- Hambrick Inc. (OH)
- Impact Communications (OH)
- Indyne Inc. (OH)
- Larry Kaufman (MA)
- Metcut Research Associates (OH)
- Modern Technologies Corp.–MTC (OH)
- N&R Engineering (OH)
- Parker Hannifan (OH)
- Philips Analytical X-Ray (PA)
- Science Application International Corp. (CA)
- SEST (OH)
- Special Metals Corp. (KY)
- Sun Valley Tech. (CA)
- Taitech (OH)
- TRW Inc. (CA)
- UES Inc. (OH)
- Woodward FST Inc. (MI)
- Wyman Gordon Company Inc. (TX)

Academic Institutions

- Brown University (RI)
- Case Western Reserve University (OH)
- Cleveland State University (OH)
- Florida A&M University (FL)
- Hampton University (VA)
- Massachusetts Institute of Technology (MA)
- Michigan Tech. University (MI)
- Mississippi State University (MS)
- North Carolina A&T University (NC)
- Northwestern University–Evanston (IL)
- Ohio Aerospace Institute (OH)
- Penn State University (PA)
- Princeton University (MD)
- Purdue University (IN)
- Rensselaer Poly Institute (NY)
- Rice University (TX)
- Stanford University (CA)
- State University at New York (NY)
- Syracuse University (NY)
- Tennessee State University (TN)
- Tuskegee University (AL)
- University of Akron (OH)
- University of Calif–Irvine (CA)
- University of Cincinnati (OH)
- University of Florida (FL)
- University of Indiana at Urbana (IN)
- University of Kentucky (KY)
- University of Michigan–Ann Arbor (MI)
- University of Minnesota (MN)
- University of Missouri–Rolla (MO)
- University of Pittsburgh (PA)
- University of Rhode Island (RI)
- University of Toledo (OH)
- Virginia Commonwealth University (VA)

Resource Investment Participants



Appendices

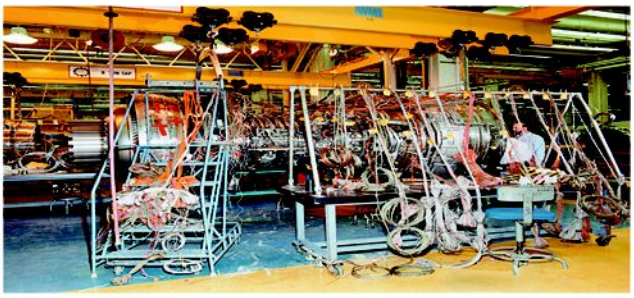
Appendix A: FY2002 Level One Milestone Technical Highlights

System Studies Identify High Temperature Wireless Data Communication as a Key Technology in Intelligent Propulsion

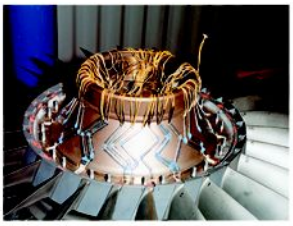
Point Of Contact:
Dr. Carolyn Mercer
NASA Glenn
Research Center

Technical Lead:
Dr. Gary Hunter
NASA Glenn
Research Center

Actual Date of Accomplishment:
April 30, 2002



Development Engine Requires 1300 Wires for Data Communication. Wireless technology eliminates the need for wires



Fan Wired for Data

Compressor Wired for Data

Project: Intelligent Propulsion Controls, Ultra-Efficient Engine Technology (UEET), Vehicle Systems

Enterprise Objective Supported:
Revolutionize Aviation

Relevant Level 1 Milestone: Controls Architecture/ Payoff Studies

Milestone Objective: Identify system benefits of intelligent engine technologies.

Milestone Minimum Success Criteria: Comparison of benefits obtainable from various technologies.

Impact of Technology: High-temperature wireless data communication was identified as one enabling technology to achieve several objectives since the elimination of wires in the engine will result in increased reliability and affordability as well as reduced engine weight and complexity.

Shown: A development engine and components wired for data communication.

Accomplishment/Relation to Milestone: Current technologies associated with intelligent propulsion were investigated and assessed against the UEET goals.

Validation of Milestone Completion:
Reports written.

Next Steps:

- Pursue the development of high-temperature Silicon Carbide material which will enable control system devices throughout the compressor and LP turbine.
- Continue high-temperature sensor development and supporting technologies in the areas of materials, electronics, and processing to enable durability in extreme environments
- Complete the system studies to aid in the identification of a suitable demonstration for the resulting technologies

Integrated Component Technology Demonstration (ICTD) Plan for Small Thrust Class Engines

Point of Contact:
Mary Jo Long-Davis
NASA Glenn
Research Center
(714-08)

Actual Date of Accomplishment:
June 30, 2002

Williams VJET II Twin Turbofan General Aviation Demonstrator

FJX-2 General Aviation Propulsion (GAP) Engine

Project: Integrated Component Technology Demonstrations, Ultra-Efficient Engine Technology (UEET), Vehicle Systems

Enterprise Objective Supported: Goal 1: Revolutionize Aviation/Objective 2: Reduce Emissions

Relevant Milestone: System Studies & Technology Demo Plans Delivered to NASA for Small Thrust Class Engines from the Contractors (Williams, Honeywell, Allison-Rolls Royce North America)

Milestone Objective: Complete Integrated Component Technology Demonstrations Plan for Small Thrust Class Engines

Milestone Minimum Success Criteria: Develop an Integrated Component Demonstration Plan for collaborative tests of engine demonstrators incorporating UEET technologies for large and small thrust class engines. (Note: the plan for large thrust class engines was completed in FY01).

Impact of Technology: Provide U.S. industry a means to conduct technology demonstration tests of advanced turbine engine components and materials as part of an integrated system (TRL 6). Provide significant technology risk reduction to the contractors and confidence in the technologies to facilitate product insertion programs.

Shown: Williams VJET II Twin Turbofan General Aviation Demonstrator and FJX-2 General Aviation Propulsion (GAP) Engine.

Accomplishments/Relation to Milestone: System studies were conducted by the engine companies to define innovative propulsion systems and determine individual benefits of advanced technologies for small thrust class applications.

Validation of Milestone Completion: High payoff/high risk technologies were determined by conducting benefit assessments. Plans were formulated to develop these high priority technologies to Technology Readiness Level of 6 as part of integrated system demonstrations.

Next Steps: Working with industry to determine which high-risk/high-payoff technologies will be matured to a Technology Readiness Level of 6 as part of the UEET program in the FY2006 – 2007 timeframe.

Integrated Component Technology Demonstration (ICTD) Plan for Access to Space Engines

Point of Contact:
Mary Jo Long-Davis
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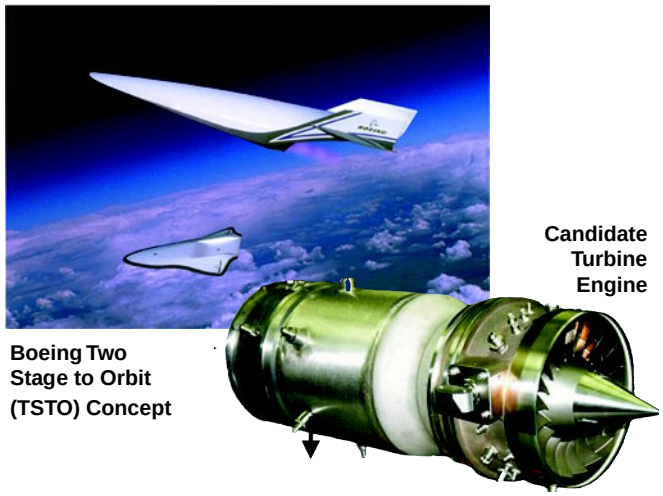
(714-08)

Actual Date of Accomplishment:
July 23, 2002



Project: Integrated Component Technology Demonstrations, Ultra-Efficient Engine Technology (UEET), Vehicle Systems

Enterprise Objective Supported: Goal 1: Revolutionize Aviation/Objective 2: Reduce Emissions

Relevant Milestone: System Studies & Technology Demo Plans Delivered to NASA for Access to Space Engines from Contractors (Allison Advanced Development Corporation)

Milestone Objective: Complete Integrated Component Technology Demonstrations Plan for Access to Space Engines

Milestone Minimum Success Criteria: Develop an Integrated Component Demonstration Plan for collaborative tests of engine demonstrators incorporating UEET technologies for access to space engines.

Impact of Technology: Provide U.S. industry a means to conduct technology demonstration tests of advanced turbine engine components and materials as part of an integrated system (TRL 6). Provide significant technology risk reduction to the contractors and confidence in the technologies to facilitate product insertion programs.

Shown: Boeing Two Stage to Orbit Concept and Candidate Turbine Engine.

Accomplishments/Relation to Milestone: A system study was conducted by the engine company to determine individual benefits of advanced technologies for access to space applications—looking for dual-use technologies. The study effort indicated that several of the UEET technologies being developed for commercial applications can also be incorporated into future Access to Space turbine engines.

Validation of Milestone Completion: High payoff/high risk technologies were determined by conducting benefit assessments. Plans were formulated to develop these high priority technologies to Technology Readiness Level of 6 as part of integrated system demonstrations.

Next Steps: Working with industry to determine which high-risk/high-payoff technologies will be matured to a Technology Readiness Level of 6 as part of the UEET program in the FY2006–2007 timeframe.

Ceramic Thermal Barrier Coating/Process Selected

Point of Contact:
Robert Draper
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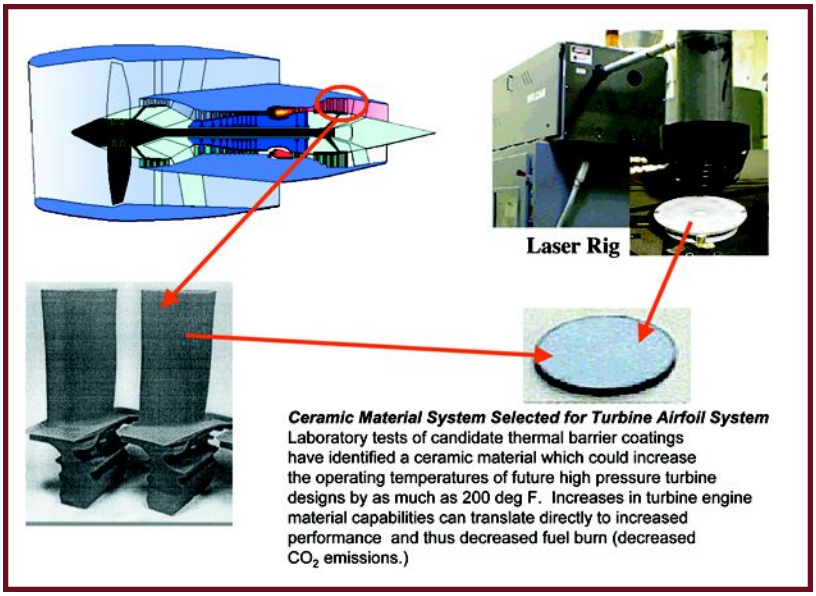
(714-05)

Technical Lead:
Robert Miller
NASA Glenn
Research Center

Actual Date of Accomplishment:
September 2002



Ceramic Material System Selected for Turbine Airfoil System
Laboratory tests of candidate thermal barrier coatings have identified a ceramic material which could increase the operating temperatures of future high pressure turbine designs by as much as 200 deg F. Increases in turbine engine material capabilities can translate directly to increased performance and thus decreased fuel burn (decreased CO_2 emissions.)

Project: Materials and Structures for High Performance, Ultra-Efficient Engine Technology Program (UEET), Vehicle Systems

Enterprise Objective Supported:
Revolutionize Aviation

Relevant Milestone: Turbine Airfoil System, Low Conductivity Ceramic Material System Selected (Coating/Process)

Milestone Objective: 2R2—To demonstrate at least one additional concept for the reduction of other emittants.

Milestone Minimum Success Criteria: Relative thermal conductivity must be reduced by at least one-half the baseline (to meet minimum exit criteria of a 200ºF improvement).

Impact of Technology: This new coating will significantly increase temperature capability of both high-pressure turbine and combustor liner components. Laboratory tests of candidate thermal barrier coatings have identified a ceramic material that could increase the operating temperatures of future high-pressure turbine designs by as much as 200ºF. Increases in turbine engine material capabilities can translate directly to increased performance and thus decreased fuel burn (decreased CO_2 emissions).

Accomplishment/Relation to Milestone: Candidate ceramic coating materials were prepared and evaluated using a combination of plasma spray and physical vapor deposition. Coatings were screened for thermal conductivity and resistance to sintering in NASA's unique high heat flux laser rig. The selected coating system will be scaled up for processing of turbine blades.

Validation of Milestone Completion: +300 ºF capability demonstrated (meets goal). Coupons survived 1200 cycles (100 hot hours) at 2480 ºF surface temperature/1940 ºF interface (meets goal). Post-exposure thermal conductivity is 40% of baseline for same time/temperature (meets metric minimum goal of 50% reduction, and approaches 33% ultimate goal.

Next Steps: Further processing modifications could further improve capability. An alternative use of the material is to apply as a thinner coating, while maintaining current component temperatures, thus reducing component, subsystem and engine weight.

2200°F Ceramic Matrix Composite (CMC) Liner Demonstration Complete

Point of Contact:
Mary Jo Long-Davis
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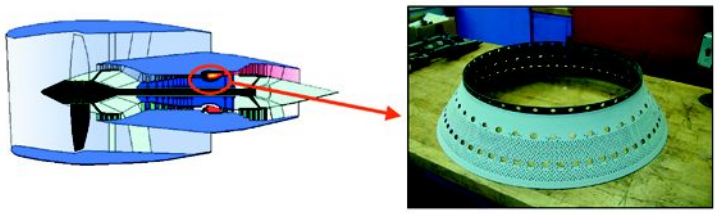
Research Center
(714-08)

Technical Lead:
Dave Brewer
NASA Glenn
Research Center

Actual Date of Accomplishment:
March 30, 2002



Advanced Ceramic Material For Engine Combustor Successfully Completes Rig Test
A full scale (CFM56 engine) CMC combustor liner test was completed at GE Aircraft Engines (GEAE) which demonstrated the technical readiness (TRL5) of the material system to be demonstrated in an engine test in FY2003. This TRL6 test will be partnership effort between NASA and GEAE and will represent the final step of a multi year technology transfer process to the U. S. industry. CMC combustor liners utilized in future commercial engine designs will result in reduced emissions levels (primarily NO_x).

*Ceramic Matrix Composite (CMC)

Project: Integrated Component Technology Demonstrations, Ultra Efficient Engine Technology (UEET), Vehicle Systems

Enterprise Objective Supported: Goal 1: Revolutionize Aviation/Objective 2: Reduce Emissions

Relevant Milestone: Complete 2200°F CMC Liner Demo (Level 1 Program Milestone)

Milestone Objective: To design and demonstrate the feasibility of an alternate fiber architecture as well as manufacture a set of full-scale liners to be used for the demonstration the cyclic durability of a SiC/SiC combustor liner in a rig test. Additionally, alternate methods of manufacturing the CMC liners were to be investigated. All objectives of the current effort were achieved.

Milestone Minimum Success Criteria: The exit criteria was to complete fabrication of a set of full-scale liners and conduct a rig test to provide data to enable a go/no-go decision to be made regarding a follow-on engine test. The minimum success for this milestone has been met with the completion of the rig test.

Impact of Technology: CMC combustor liners utilized in future commercial engine designs will result in reduced emissions levels (primarily NO_x).

Shown: CFM56 CMC liner with an Environmental Barrier Coating (EBC) applied and laser drilled cooling holes.

Accomplishment/Relation to Milestone and ETO: Specifically, these silicon carbide fiber reinforced silicon carbide (SiC/SiC) ceramic matrix composite (CMC) combustor liners are being developed to meet the NO_x durability and performance goals of the UEET program.

Validation of Milestone Completion: Data from rig test and full scale set of CMC liners fabricated.

Next Steps: A final report documenting the results of the CMC liner development effort and rig test is being prepared. Based upon the liner performance during the rig test, the decision has been made to proceed onto a production CFM56 engine test of the CMC liners which will likely occur within the next year.

Initial Low NOx Demonstrated in a Combustor Sector

Point of Contact:
John Rohde
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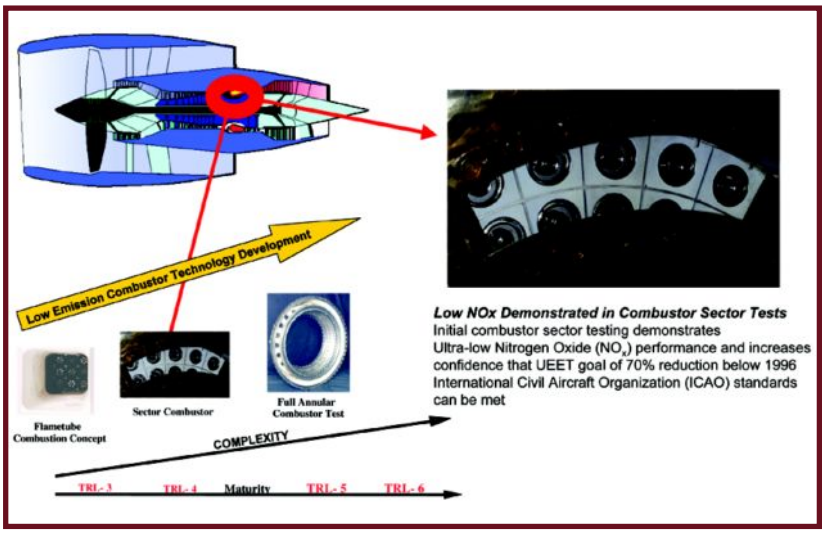
Technical Lead:
Paul Penko
NASA Glenn
Research Center

Actual Date of Accomplishment:
July 2002



Project: Emissions Reduction, Ultra-Efficient Engine Technology (UEET), Vehicle Systems

Enterprise Objective Supported: Revolutionize Aviation

Relevant Milestone: 2R2—To complete sector testing of a low-NO_x combustor concept capable of a 70% reduction in NOx from 1996 ICAO baseline.

Milestone Objective: To demonstrate in an initial sector rig test a NO_x reduction of 70% from the 1996 ICAO regulation over the landing/takeoff cycle with a minimum success level of 65% reduction.

Milestone Minimum Success Criteria: Complete sector evaluations of a combustor capable of 70% reductions in Oxides of Nitrogen.

Impact of Technology: These low emission sector combustor tests provide industry with the confidence that future low emission combustor can be developed that are capable of meeting the UEET 70% NO_x reduction goal, over the landing and takeoff cycle, for future environmentally friendly commercial engines.

Accomplishment/Relation to Milestone and ETO: Low emission TAPS 10-cup dual-annular type sector combustor rig emissions testing was conducted in Cell 19 at GE Aircraft Engines, Evendale, Ohio, in July 2002. This sector combustor rig was run at high temperatures and pressures typical of engines in commercial service today.

Validation of Milestone Completion: Emission tests were conducted at the landing and takeoff conditions and cruise conditions that future UEET environmentally friendly commercial engines will operate over and detailed exhaust emission measurements of Oxides of Nitrogen (NO_x), Carbon Monoxide (CO), Unburned Hydrocarbons (UHC) and Smoke.

Next Steps: Sector combustor rig testing will continue next fiscal year at still higher pressures (50:1 to 55:1 pressure ratio) typical of future environmentally friendly commercial engines, at NASA Glenn's Advanced Subsonic Combustion Facility.

Future Plans

Future Plans

Significant technical and programmatic accomplishments are anticipated in Fiscal Year (FY) 2003 for the UEET Program. Specifically, two technology readiness level (TRL) 6 engine demonstrations will be accomplished in partnership with General Electric (GE) Evandale, OH. Separate engine tests will be conducted of an aspirating seal and Ceramic Matrix Composite (CMC) liner for combustor applications. Successful completion of these tests will provide the technical foundation to speed the technology transition into future commercial and military engines. These two technologies will both contribute to reduced fuel burn, and therefore reduced emissions. In both cases, the corporate partner will contribute engine testbeds as well as costs associated with testing, which significantly reduces the government's dedicated resources to complete TRL6 demonstrations.

Another major FY 2003 accomplishment for UEET will be the completion of several combustor sector tests. These experimental efforts, conducted in partnership with our turbine engine corporate partners, will evaluate various approaches for achieving the program goal of 70% LTO NO_x reduction in combustor sector rigs (TRL4). These sectors represent more realistic designs than the laboratory flame tube rigs that were used in previous years to establish the most promising approaches to carry into sector designs and investigate the fluid physics associated with ultra low emissions concepts. The most promising concepts for achieving the UEET NO_x emissions goal will be selected at the end of FY 2003 for technology development continuation and maturation to full annular rig testing (TRL5) in the 2004–2006 time period. NASA's UEET-developed technologies will reduce risk for turbine engine corporate partners, allowing them to invest their own resources to develop future low-emissions product combustors that can be incorporated in new engine designs as well as combustors that can be incorporated into current designs to reduce the NOx emissions levels and meet expected future international standards/requirements.

The final design of the Dual Spool Turbine Facility (DSTF) will be completed in FY 2003 and a construction contract will be awarded through open competition. The DSTF facility will become operational in FY 2005 and will provide NASA and its partners—GE, Pratt & Whitney, Air Force Wright Laboratories, and Ohio State University—a unique test facility to study and understand the fluid physics of closely-coupled, highly-loaded turbine concepts. Future commercial, military, and access-to-space turbine engine systems will require fewer stages to reduce system weight while maintaining high levels of performance and operability. The DSTF will allow for orderly, disciplined research to be conducted that will significantly improve physical understanding of the aerodynamics associated with such turbine concepts. This improved understanding can be applied to develop and validate design tools that can be utilized by corporate partners in future product engine designs.

Programmatically, UEET will complete a major technology benefits assessment at the end of the fiscal year. This effort will integrate the projected impacts of all the technologies being developed by the UEET Program on a group of subsonic and supersonic reference or vision vehicles. These studies will quantify the reduction in both fuel burn reduction and NOx reduction that could be forecast if the technologies were incorporated in future engine designs. Since the UEET technologies are at varying TRLs, these studies will also assess the uncertainty (or risk) in these technology impacts. The reference or vision vehicles are government baselines and not meant to be identical to any one corporate partner's designs, but can provide an objective assessment of UEET technologies' expected impact. These studies will also contribute to an evaluation of the technology prioritization in UEET's portfolio.

UEET will continue to place top priority on exploring and developing meaningful partnerships with Department of Defense (DoD) programs such as the IHPTET (Integrated High Performance Turbine Engine Technology) and the newly-formed VAATE (Versatile Affordable Advanced Turbine Engine) programs. These partnerships will enable each program to leverage relevant technologies being developed in other programs as well as provide opportunities

for joint technology development. These efforts will reduce the probability of duplicating efforts, and therefore poor utilization of federal resources. NASA's Administrator, Sean O'Keefe, has committed that the Agency will work more closely with and support DoD in providing for national security needs. We in UEET are totally committed to supporting his vision.

In FY 2002, NASA initiated a significant change in the programmatic structure of the Aerospace Technology Enterprise. Specifically, these changes included the development of Agency budget theme areas, including one for Aeronautics Technology. Three programs have been formed under the Aeronautics budget theme area. One of these programs is the Vehicle Systems Program. As the name suggests, the Vehicle Systems Program will be responsible for the development of airframe, propulsion, and flight systems technologies required for future subsonic and supersonic air vehicles. UEET will become one of the projects that comprise the Vehicle Systems Program. UEET's goals and objectives (and therefore importance) will not change even though we will become a project. We in UEET are totally committed to the success of the Vehicle Systems Program and in FY 2003 we will continue to provide our full support to its creation.

We in the UEET Program are working with our corporate partners to develop a cost-effective plan for maturing the UEET technologies to a TRL6 level through cooperative efforts utilizing existing engine testbeds. We believe these TRL efforts are critical risk reduction efforts for accelerating the technology transition/insertion process. We will take this plan to NASA's Aeronautics theme and Vehicle Systems Program management in FY 2003 for their considered support.

We remain steadfast in our belief that the future for the UEET Program is very promising. We continue to receive extremely positive feedback from our customers and stakeholders that we are pursuing, and indeed developing the right turbine engine technologies for our U.S. aeropropulsion community. We are committed to working even harder in FY 2003 to ensure that not only will we have a successful year, but that we will further strengthen our prospects for out-year successes as well. Air vehicles, both commercial and military, will be powered by turbine engine-based propulsion systems for the foreseeable future. It is critical to our country's economic and military strength that we produce propulsion systems of world class capability. The UEET Program is playing a key role in maintaining the Nation's global leadership in turbine engines through its technology development and transition process.

R.J.S

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